Weighted Dominating Set Based Energy Efficient Routing in Wireless Ad Hoc Network with Stable Nodes

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Abstract

A mobile ad hoc network (MANET) is a self-configuring, infrastructure-less network with inherent flexibility.Mobility of nodes in these networks often results in changes in network topology due to the formation of new links and the extinction of the old ones, which may result in packet losses.In spite of such daunting challenges, MANETs promise to be an ever-present technology and have proven useful in a wide range of areas.Researchers are interested in assessing the reliability and stability of such dynamically changing networks.The proposed distributed algorithm reduces the frequent route failures by incorporating route stability into routing which helps to sustain network operations over an extended period of time. Here, a subset of network node named Weighted Connected Dominating Set (W – CDS) is selected based on the stability factor, which consists of link stability, node degree and mobility to achieve the maximum network lifetime. Then, the redundant nodes are removed by the pruning technique considering energy parameter. The simulation results show that the proposed protocol provides data forwarding support with fewer CDS nodes and thereby increases the lifetime of the network. It creates less interference and consumes less energy when compared to the other existing techniques.

Keywords: MANET; Dominating set; Network lifetime; Energy efficiency; Stability
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1. INTRODUCTION

Ad hoc networks consist of wireless mobile nodes such as PDAs, notebook computers, mobile phones, or hand-held devices that communicate with each other through wireless channels.Batteries, low bandwidth, and dynamic topology are important characteristics of these networks.Ad hoc peer-to-peer communications can be made possible with MANETs [1] by providing an instant, distributed, peer-to-peer communication solution.During an emergency scenario, it is assumed that battery-powered devices cannot be recharged.If the nodes are within transmission range of each other, then they can communicate directly; otherwise, messages must be routed through intermediate nodes.In emergency MANETs, since mobile nodes usually have homogeneous lifetimes, energy efficiency, quick response time, as well as stability are equally important.A dynamic and adaptive routing protocol allows the formation of ad-hoc networks quickly, and during the rescue operations, it guarantees efficient communications.

According to Sheu et al. [2], a stable dominating set can be produced based on the stability of links.It is said that the link is weak if the beacon signals received on it are below a threshold.Each node is considered in decreasing order of the number of non-weak links associated with it.According to Leu et al. [3], both dynamic and static CDS can be constructed based on received signal strength.Basagni [4] uses the Mobility Adaptive Clustering Algorithm (MACA) to develop weakly clustered datasets with slow-moving nodes.The weakly-CDS generates a subgraph with weak connections, which is the result of dominating nodes and their neighbors. Therefore, nodes serving as cluster-heads are responsible for coordinating neighboring nodes.Cluster-heads move randomly, so fast-moving nodes are more likely to encounter other cluster-heads sooner than slow-moving ones.It is expected that the open neighbor sets of fast-moving nodes will change more than those of slow-moving nodes.Thus, their algorithm selects nodes that move slowly, which are more likely to have stable connections.An et al. [5] investigate the creation of a CDS based on nodal movement.Using this protocol, nodes periodically exchange information about their positions and velocity.In a node, relative velocities and relative mobility between neighbors are calculated.An algorithm for selecting a stable route has been proposed by Wang et al. [6].A route's weight is calculated according to three factors: its expiration time, its error count, and its hop count.

The authors of Sakai et al. [7] propose a novel algorithm for handling mobility to improve CDS recovery in mobile environments.Bao et al. [8] propose a distributed topology management algorithm for constructing and maintaining the minimal dominating set which works well with the 2-hop neighboring information. To address the issue of topology control in homogeneous and heterogeneous networks, Al-Karaki et al. [9] propose a simple, fixed and scalable virtual wireless backbone.An efficient routing scheme is created by using the fixed backbone, called the Virtual Grid Architecture (VGA), created through a simple and novel zoning scheme.Yen et al. [10] propose an MPR-based broadcasting scheme to limit RREQ packet flooding.The nodes selected as MPR nodes helps to rebroadcast the RREQ packet rather other nodes in the network just send/receive the packets and will not rebroadcast. It results in the optimized route selection and adapts to the network changes. A broadcasting protocol based on MPR is proposed by Moulahi et al. [11].

The organization of the paper is arranged as: Section 2 discusses about the existing CDS construction techniques; Section 3 discusses the stable routing based on connected dominating set. Result analysis and Conclusion is discussed in Section 4 and 5 respectively.

2. Related Work

Most of the existing routing protocols in literature uses hop count as the selection metric to discover routes. The mobility of the nodes affects both the selected paths quality and durability and is found to be unstable. A routing protocol generally uses a broadcasting mechanism to obtain a new route (i.e.) route discovery approach. Here, the flooding of 'Route Request' (RREQ) packets leads to network congestion and more energy is consumed. Frequent route change leads to frequent route computation process. Therefore, it is essential that routing protocols must incorporate the nodes mobility information and residual energy to adapt to frequent node and network changes. The stability of path is an important criterion while designing multi-hop ad hoc communication protocol.Stability, energy efficiency and quick response time are equally essential for routing, as these mobile nodes have homogenous life time.

ChuanwenLuo et al.[12] proposed a novel distributed algorithm by constructing a dominating set based on link and degree followed by connecting tree using connectors.

This procedure reduces the number of connectors added to the dominating set. A multicast communication with Quality of Service (QoS) support is designed by Gaurav Singal etal.[13] to determine the reliable forwarding node. These nodes are selected based on the Link Stability Cost Function (LCF) incorporated with the QoS aware routing. The multi objective cost function includes the hop count, signal strength and contention count together constitutes better link/route quality. An energy efficient connected dominating set with critical nodes to improve the reliability of the wireless sensor network is proposed by OrhanDagdeviren etal.[14]. Here, two localized distributed algorithms are determined for predicting the status of the nodes as either critical or non-critical. Initially, the critical and non-critical dominating nodes are identified from the two-hop local sub graph. Then, the status of all nodes is predicted using depth first search algorithm without traversing the entire network. This algorithm finally obtains all critical nodes with minimum energy consumption.

Djamel Djenouri&MiloudBagaa[15] used the concept of energy aware constrained relay node deployment for data forwarding in sensor network. The nodes are categorized as energy rich nodes and energy limited nodes for the functionality of relaying packets and for sensing and coverage respectively. Here, a minimum number of relay nodes are added to ensure coverage and prolong the network lifetime by taking advantage of weight function. The final obtained nodes form the minimum weighted connected dominating set (MWCDS) in a weighted graph. Gaurav Khanna et al. [16]proposed a Monte Carlo simulation by determining the link expiration time and border time to evaluate the reliability of the MANET. It uses mobility factor and link between the nodes, but failed to discuss the energy consumption of the nodes. This affects the network lifetime and reliability assessment.

The research work proposes a distributed algorithm to design weighted dominating set based energy efficient routing. The proposed algorithm uses a stability factor consisting of link stability, node degree and mobility to achieve maximum network lifetime.The obtained weighted connected dominating set (W-CDS) is pruned to remove redundant nodes which results in fewer CDS nodes for data forwarding. The major design objective of W-CDS is construction of virtual backbone with quality nodes and minimum dominator nodes. In this protocol, the nodes play two roles as dominator and dominate. The dominator node relays / rebroadcasts the messages it receives while the dominate node just receives the message.

3. WEIGHTED DOMINATING SET BASED ENERGY EFFICIENT ROUTING ALGORITHM (W-CDS)

3.1 Network Model and Problem Statement

An ad hoc network is modelled as a vertex – weighted, an undirected and connected graph $G = (V, E, WT)$ with vertex weight function $WT_x : V \rightarrow R^+$, where $V = \{x_{1,} x_2, \dots . x_n\}$ denotes the set of mobile nodes and $E = \{ (x_i , x_j)/ \ i \le n, j \le n\} \subseteq V \times V$ represents the communication links between the nodes. Here, $WT_x = \{WT_i \forall \ i \in V\}$ is the set of weights corresponding to that node. A homogenous network is deployed in 2D plane where the nodes are assumed to have same transmission range. An edge is said to exist between the two nodes x and y, if they are within the transmission range of each other. The stability metric is WT_x which is associated with the communication links and the main objective is to obtain minimum size CDS with improved network lifetime.The problem is to find a W-CDS which is found to be more stable and extend the network lifetime.

Definition 1: Relay (x)**:** Given a graph $G(V, E)$, for a node $x \subseteq V$, $\text{Relay}(x) = \{y | y \ \in N_1^x\}$ such that$N_2^x = U_{y \in Relay(x) N_1^y}$.

Definition2: Weighted Connected Dominating Set (W-CDS):Given a graph $G = (V, E, WT_x)$ with the node weight function$WT_x : V \rightarrow R^+$, with the objective to find minimum size CDS of graph G such that it has maximum weight in total.

4061

3.2 Algorithm for Weighted Connected Dominating Set Construction

The construction of the proposed weight based dominating set routing consists of three phases as Neighbor discovery phase, CDS formation phase and Route maintenance phase. The nodes in the network exchange 'HELLO' packets periodically to its neighbors. The HELLO message of node x contains information as $< WT_x, N_1(x) >$. When the node x receives a hello message from one of its neighbors in $N_1(x)$, it then updates the two-hop neighbor table. Finally, this local topological information is used in selecting the dominating nodes. Before initiating the neighbor discovery phase, each node in the network calculates the weighted metric to estimate the stability of the particular node.

3.2.1 Weight Calculation

The proposed weight WT_x for a node x consists of three metrics, taking into consideration the link stability $LS(x)$, node mobility $MOB(x)$ and node degree $D(x)$. Here, the link stability metric is used to calculate the communication stability within its neighbors. The mobility metric helps to predict the speed of the node as discussed in Zifen Yang et al. [17]. In addition, $MOB_{min}^{(x)}$ is the minimum mobility factor with the value of 0.01 when the mobility metric $MOB(x)$ = 0. The weight of the node x is calculated as,

$$WT_x = \begin{cases} \frac{LS(x)}{MOB(x)} |D(x)|, \ if\ MOB(x) > 0 \\ \frac{LS(x)}{MOB_{min}^{(x)}} |D(x)|, Otherwise \end{cases} \quad (1)$$

As in Equation 1, the value of link stability, mobility and node degree are calculated as shown in Equations4,5 and 6 respectively.

- **Link stability calculation**

The link stability metric is calculated based on the Received Signal Strength (RSS). The link stability between node x and node y is defined as in Equation 2

$$L_{xy} = \frac{1}{(1-\Delta RSS_{xy})} \quad (2)$$

Assume ΔRSS_{xy} is termed as the variation of received signal strength between nodes x and node y with,

$$\Delta RSS_{xy} = \frac{(RSS_{xy}^{t+1} - RSS_{xy}^{t})}{t} \quad (3)$$

where the following condition prevails , when

(a) $\Delta RSS_{xy} = 0$: Distance between the nodes is unchanged.
(b) $\Delta RSS_{xy} > 0$: Distance between the two nodes is closer.
(c) $\Delta RSS_{xy} < 0$: Distance between the two nodes is increasing.

And finally, the link stability of the node x is given as in Equation 4.

$$LS(x) = \sum_{\forall y \in N_1(x)} L_{xy} = \sum_{\forall y \in N_1(x)} \frac{1}{(1-\Delta RSS_{xy})} \quad (4)$$

- **Calculation of mobility metric**

The mobility factor is calculated as the percentage of neighbors which remains between the time t and $t+1$ (i.e.) between the two consecutives 'HELLO' packets. With the symmetric difference between the sets A and B, the algorithm obtains more stable nodes as the dominating node as stated in Equation 5

$$MOB(x) = \frac{|N_1^{t+1}(x)/N_1^t(x)|}{|N_1^{t+1}(x) \cup N_1^t(x)|} \quad (5)$$

- **Degree metric calculation**

The degree of node x is calculated as the number of neighbors of node x divided by the maximum degree of nodes in $N_1(x)$.

$$D(x) = \frac{|N_1(x)|}{\max\{|N_1^i|; \forall\, i \in N_1(x)\}} \quad (6)$$

- **Energy calculation**

The energy metric plays a major role in increasing the lifetime of the CDS and by which more energy rich nodes are selected. The $E(x)$ of a node x is the remaining energy in x divided by the maximum energy of nodes in $N_1(x)$which is described in Equation 7

$$E(x) = \frac{E_{rm}^x}{max\{E_{rm}^i; \forall\, i \in N_1(x)\}} \quad (7)$$

The obtained value $E(x)$ is used in marking process to prune the redundant nodes in the connected dominating set.

3.2.2 CDS Formation Phase

According to marking phase, all the nodes are marked 'WHITE' in color. The Table1 lists the notations used in the algorithms. After the 'HELLO' message transmission, a node x marks itself as a dominator node and marked 'BLACK' in color as discussed in Algorithm 1. A node is said to be relay / intermediate node if it has two disconnected neighbors. A node x is covered by another node y, when $N_1(x) \subseteq N_1(y)$ and $WT_x \le WT_y$. In few cases, relay nodes become a dominatee node if it is not covered by any neighbor. Additionally, dominatee node not covered by any pair of connected neighboring nodes; it becomes a dominator node (BLACK color). A dominator node is marked in 'BLACK' and the dominatee node in 'GREY' color. Finally, all the black nodes form the local-CDS of the network. This reputation process involves only two messages as, information about two-hop neighbors and intimate neighbors about its final decision.

Table 1 - Notations and descriptions

Notation	Description
n	Total number of nodes in the network
V	Set that contains all nodes in the network
E	Set that contains all edges in the network
$E\ (x)$	Residual energy at node x
$D\ (x)$	Node degree of node x
$ID\ (x)$	Node ID of node x
$MOB(x)$	Mobility metric of node x
$V(x)$	Velocity of node x
$LS(x)$	Link stability of node x
WT_x	Weight of node x
$MOB_{min}^{(x)}$	Minimum mobility factor with value 0.01
RSS_{xy}	Received Signal Strength (RSS) between node x and node y
ΔRSS_{xy}	Variations in RSS between node x and node y
E_{rm}^x	Remaining energy at node x
E_{in}^x	Initial energy at node x

$N_1(x)$	$\{y\|(x,y) \in E\}$
$N_1^t(x)$	$N_1(x)$ at time 't'
$N_2(x)$	$\{z\|y \in N_1(x) \land z \notin N_1(x) \land (y,z) \in E\}$
$N\ (x)$	Open neighbor set of node x
$N[x]$	Closed neighbor set of node$x$

The Table 2 represents the dominating set selection algorithm and these are followed by all the nodes in the network. The main idea algorithm is as follows: when a node x has two unconnected neighbors, it enters relay state and if yes, the node x then becomes dominatee node when WT_x is high among the one-hop neighbors and also not covered by any of its neighbor y. Finally, node x becomes dominator when its weight is largest $WT_x \geq WT_y\ and\ WT_x \geq WT_z$ but not covered by any two of its neighbors. Node x is marked BLACK in color and the set of black colored nodes form the CDS as represented by 'C'.

Table 2- Dominating set construction

Algorithm1: Algorithm to construct dominating sets
Input: a connected graph $G = (V, E)$
Output: dominating set (C)
Data: Marking process – node x (WHITE, BLACK, GREY)

// Every node in the network undergoes marking process
Step 1: C = ∅ ; $x = relay \neq dominator \neq dominatee = false$
Step 2: **for** each $y, z \in N_1(x)$ do
Step 3: **if** $y \neq z\ \&\&\ z \notin N_1(y)$**then**
Step 4: relay (x) = true
Step 5: **end if**
Step 6: **end for**
Step 7: **if** relay (x)**then**
Step 8: dominatee(x) = true
Step 9: **for** each $y \in N_1(x)$**do**
Step 10: **if**$N_1(x) \subseteq N_1(y) \&\& WT_x \leq WT_y$ **then**
Step 11: dominatee(x) = false
Step 12: **end if**
Step 13: **end for**
Step 14: **if**dominatee(x) then
Step 15: dominator(x) = true
Step 16:**for**each$y$, z $\in N_1(x)$**do**
Step 17: **if** y $\neq$ z && $y \in N_1(z) \&\& N_1(x) \subseteq N_1(y) \cup N_1(z)$ then
Step 18: **if** $WT_x \leq WT_y \&\& WT_x \leq WT_z$ then
Step 19: dominator (x) = false
Step 20: **end**
Step 21: **end**
Step 22: **end**
Step 23: end
Step 24: if dominator (x) then
Step 25: Color $(x) \leftarrow$ BLACK // dominator node
Step 26:else

Algorithm1: Algorithm to construct dominating sets
Step 27: Color $(y) \leftarrow$ GREY // dominatee node **Step 28:end** **Step 29:** $C \leftarrow$ nodes marked in BLACK form CDS

The local connected dominating set obtained from the previous step has redundant nodes and those nodes are removed using the following two rules defined as EL-R1a and EL-R2a which is based on the energy level as calculated in the section 3.2.1 and node ID. This helps to increase the overall network lifetime and minimizes the CDS size when compared with the rules discussed in previous chapter. Let us consider the graph induced by CDS is G', then $E(x)$ represents the energy and $D(x)$ is the node degree of x in G (i.e.) the cardinality of $x's$ neighbor set $|N(x)|$. $N[x] = N(x) \cup \{x\}$ is the closed neighbor set of x, as opposed to the open set $N(x)$.

EL-R1a: Consider the two vertices x and y in G'. The marker of y is changed to gray color if any one of the following conditions holds:

i. $N[y] \subseteq N[x]$ in G and $E(y)<E(x)$.
ii. $N[y] \subseteq N[x]$ in G and $ID(y)<ID(x)$ when $E(y)= E(x)$.

The above rule represents that; node y can be removed from the graph G' when the closed neighbor set of y is completely covered by the node x if the energy of node y is lesser than the node x. When the energy levels of the two nodes x and y are same, the node ID of the node is used to break the tie. It is clear that $G' - \{ y \}$ is still a connected dominating set of $G$where the condition $N[y] \subseteq N[x]$ holds good in all situations which infer that node x and y are connected in G'. To ensure that one and only one node is removed, a node with smaller energy level is chosen.

EL-R2a: Consider the two vertices x and z in G' as marked neighbors of the marked vertex y . The marker of y is changed to gray color if any one of the following conditions holds:

i. $N(y) \subseteq N(x) \cup N(z)$, but $N(x) \nsubseteq N(y) \cup N(z)$ and $N(z) \nsubseteq N(x) \cup N(y)$ in G
ii. $N(y) \subseteq N(x) \cup N(z)$ and $N(x) \subseteq N(y) \cup N(z)$, but $N(z) \nsubseteq N(x) \cup N(y)$ in G; one of the conditions holds
   a. $E(y)<E(x)$ or
   b. $E(y)= E(x)$and $ID(y)< ID(x)$.
iii. $N(y) \subseteq N(x) \cup N(z)$ and $N(x) \subseteq N(y) \cup N(z)$ and $N(z) \subseteq N(x) \cup N(y)$ in G; one of the conditions holds
   a. $E(y)< E(x)$ and $E(y)< E(z)$ or
   b. $E(y) = E(x)< E(z)$ and $ID(y)<ID(x)$, or
   c. $E(y) = E(x) = E(z)$ and $ID(y) = \min\{ID(y), ID(x), ID(z)\}$

The above rule depicts that, when y is covered by x and z;
Case (i) if neither x nor z is covered by the other two among x, y and z, node y can be removed fromG';
Case (ii) if nodes y and x are covered by the other two among x, y and z, but z is not covered by x and y, node y can be removed from G';
Case (iii) when each of node x, y and z is covered by the other two among x, y, and z;

node y can be removed from G'. The condition $N(y) \subseteq N(x) \cup N(z)$ implies that x and z are connected and hence $G' - \{y\}$ is still a connected dominating set. After pruning phase, the final W-CDS is obtained and the route is established through this connected dominating set from source node to destination node.

3.2.3Route Repair and Recovery Phase

The routing process is carried out through the W-CDS nodes and when a node wants to communicate with other nodes in the network, route computation is performed to obtain the shortest path. Instead of hop-by-hop routing, to improve the routing performance, source routing is applied in W-CDS for retransmission of packets. The source node initiates the process and each packet carries the complete information about the route from source to destination node including the relay nodes. These relay nodes do not maintain the routing information.

As the wireless network has dynamic topology, there is a possibility of link breakages. Hence a route recovery mechanism is carried out where the W-CDS (dominator nodes) check the next hop is one of its neighbors as instructed in the source packet and it forwards the packet. Else, route re-computation is done to find the new route to the destination and then forward the packets through the new route as stated in Algorithm 2 in Table 3.

Table 3 -Route repairing using W-CDS

Algorithm 2: An algorithm for route computation and recovery using W-CDS (Dominator nodes) **Input**: the broken node, a connected graph $G = (V, E)$ **Output**: Best shortest path selected for routing **Data**: Node x receives a data packet 'D_PKT' with destination D
Step 1: **if**$x == D$ **Step 2**: Receive(D_PKT) **Step 3**: **else** **Step 4**:next_Hop = nextN.Address (D_PKT) **Step 5**: **if** **Step 6**: neighbor_Table.lookUP (next_Hop) ≠ 0 then **Step 7**: forward (D_PKT, next_Hop) **Step 8**: new_PATH = routeRecovery (D) **Step 9**:D_PKT.SourceRoute = New_PATH **Step 10**: next_Hop = nextN.Address (D_PKT) **Step 11**: forward **(**D_PKT, next_Hop) **Step 12**: **end if** **Step 13**:**end if**

4PERFORMANCE EVALUATION

4.1Simulation Settings

This section deals with the performance evaluation of the proposed W-CDS routing protocol through simulations using NS-2.34. The experiment has 'n' number of nodes and is repeated for 50 trails with different network sizes and mobility range. The proposed algorithm is compared with the existing algorithms as in MWDS-RN [17], LDDS-CT [14], R-MCS [16] and CDS-CUT [12]. The simulation parameters used are listed in Table 4 and the performance analysis includes routing overhead, packet delivery ratio, CDS size and CDS lifetime based on the route maintenance.

Table 4 - Simulation Parameters

Parameters	Values
MAC protocol	IEEE 802.11b
Transmission range	250 m
Simulation time	600s (repeated 50 times)
Number of nodes	50 to 300 Default: 150
Mobility model	Random way point
Antenna	Omni Antenna
Propagation model	Two-ray ground
Network area	1000 * 1000 m^2
Data Traffic Type	Constant bit rate (CBR)
Packet size	512 bytes
Queue size	50 packets
Idle energy	0.013 W
Transmission power	0.667 W
Idle power	0.1 W
Bandwidth	2mbps
Receiving power	0.365 W
Maximum speed or mobility range (m/s)	5 m/s, 10 m/s, 15 m/s, 20 m/s, 25 m/s, 30 m/s Default : 20 m/s
Number of connections (4 packets /sec)	1, 3, 5 up to 20 connections Default : 10

4.2 Result Analysis

To analyze the performance of W-CDS construction algorithm, the following metrics are used as follows:

- Routing overhead: It is the total number of routing packets transmitted during the simulation period and it helps to measure the energy efficiency.
- Energy consumption: It is the total energy consumed for transmitting and receiving both the data and control packets.
- Packet delivery ratio: It is calculated as the ratio of data packets received by the destination to the total packets transmitted by the source node. This factor helps to measure the scalability and reliability of the routing protocol.
- Average CDS size: The CDS size is the fraction of the network nodes in the CDS.
- Average route length: It is average number of hops between source and destination nodes in the established path.

The achievement of all these factors comparatively increases the network lifetime with the help of W-CDS nodes.

4.2.1 Average CDS size

The Figure 1 shows the average CDS with varying network densities. The weight calculation in the proposed work combines multiple parameters such as link stability, node mobility and degree of the node for obtaining stable CDS. The CDS-CUT has higher CDS size as it obtains the state information of the critical nodes based on the node degree alone. The preference is given to the nodes that have larger number of uncovered neighbors. But in case of LDDS-CT, it constructs better non-trivial CDSs for sensor networks with uniform and random distribution of sensors.

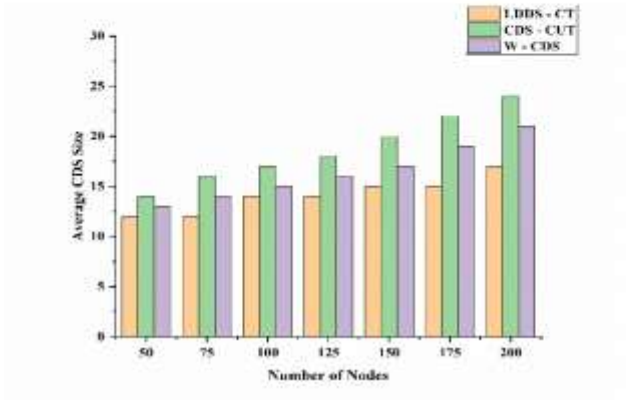

Figure 1 - Average CDS size versus number of nodes

4.2.2 Average route length

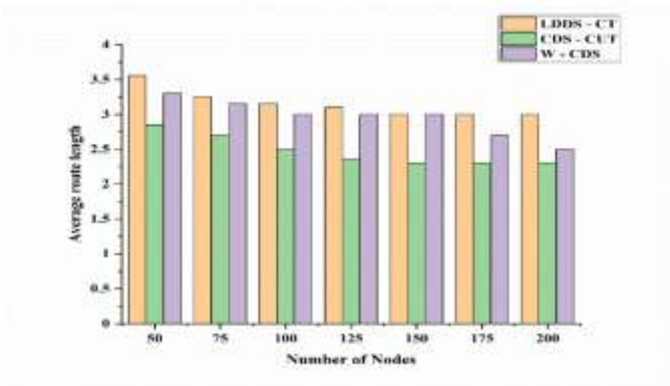

Figure 2 - Average route length

The Figure 2 clearly shows how well a routing protocol can perform over CDS. The LDDS-CT is found to have high route length as it has smaller CDS size. The routes obtained by W-CDS is longer when compared with CDS-CUT as it uses mobility factor to obtain CDS while the latter considers the CDS nodes as critical and non-critical dominator nodes by using a distributed depth-first search algorithm without traversing the whole network.

4.2.3Routing overhead

The result in Figure 3 depicts the routing overhead against node mobility / maximum speed. The overhead of all the routing protocols increases with the increased maximum node speed. This is because when node mobility increases, existing path may be broken and more RREQ packets are generated and transmitted. The reduction in the routing overhead is achieved in W-CDS as it constructs the most stable routes with the longest duration in contrast with LDDS-CT, CDS-CUT, R-MCS and MWDS-RN. The R-MCS has high routing overhead as it uses only link expiration time and border time to evaluate the reliability of MANET. Though LDDS-CT has minimum CDS, it does not guarantee an optimal network performance because the routing path is broken frequently due to the mobility of the nodes.

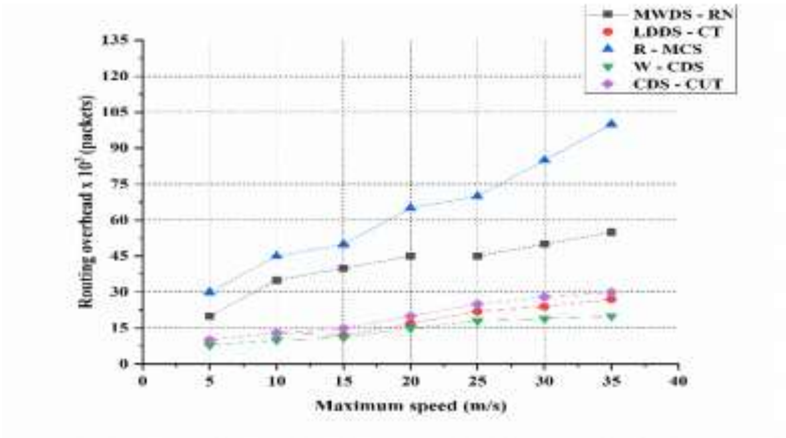

Figure 3 - Routing overhead versus maximum speed

In case of analysis, in terms of routing overhead versus network size as shown in Figure 4, it is observed that the routing overhead generated by each protocol increases as the network density increases. At high density, the overhead generated by R-MCS and MWDS-RN is increased as it does not involve the CDS nodes in the RREQ transmission. The remaining protocols CDS-CUT, LDDS-CT and W-CDS have reduced number of RREQ transmissions and are restricted only to the CDS nodes. As the CDS size grows with the increasing network size, the routing overhead of W-CDS is the least compared to MWDS-RN and R-MCS.

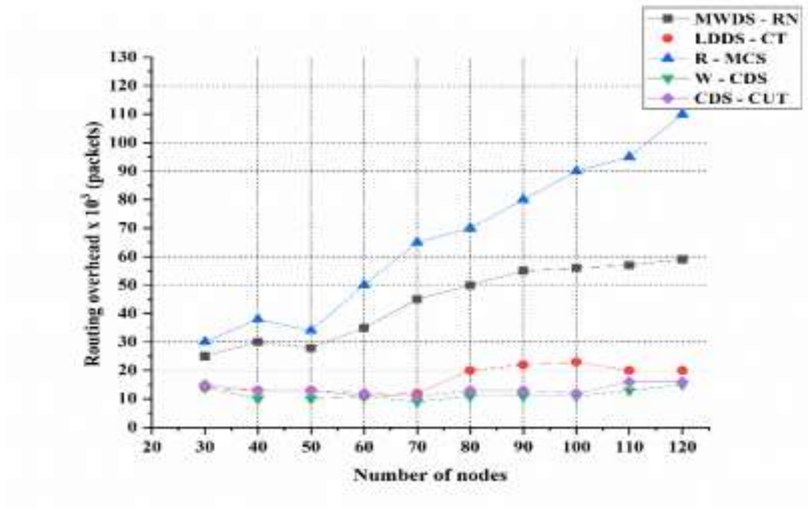

Figure 4 - Routing overhead versus number of nodes

4.2.4 Packet delivery ratio

Figure 5 shows the packet delivery ratio of the routing protocols against the maximum node speed. The results show that the packet delivery ratio decreases with the increased node mobility. This is due to the fact that the routes are highly prone to breakage as the host speed increases. The weight based CDS construction algorithm uses a link stability and mobility metric, which provides more stable nodes that are not likely to change their neighbor set rapidly. The packet delivery ratio of LDDS-CT is close to W-CDS as it has high linked stable connecting tree that are localized. In case of CDS-CUT, there is a loss of connection with the neighbors as only nodes with more neighbors are added. The R-MCS has least PDR as there are no specific CDS nodes to handle and therefore, the mobility affects the whole network.

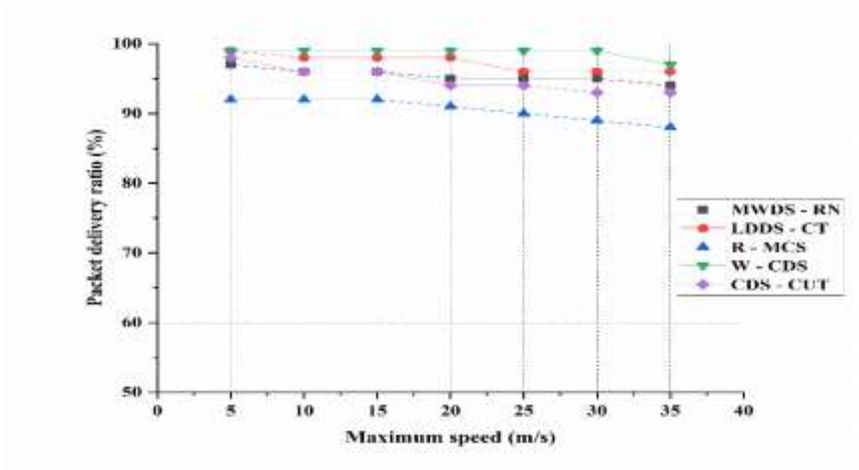

Figure 5 - Packet delivery ratio versus maximum speed

When the network density is low, the network connectivity is poor. The performance of R-MCS is dropped, when the network density increases as shown in the Figure 6. The W-CDS has high packet delivery ratio as it involves link stability and mobility metric to select the CDS and the final CDS is obtained by pruning using energy rich nodes. As these nodes are stable, it maintains high packet delivery ratio when compared to other routing protocols.Similarly, when the number of flows increases, the number of nodes initiating route discovery operation also increases. As a result, more RREQ packets are generated and transmitted which lead to a high consumption of the communication bandwidth. This leads to the delivery of fewer data packets at the destinations, thereby degrading the delivery ratio as shown in Figure 7. At offered load of 20 flows, the high delivery ratio is achieved by W-CDS with more stable nodes, when compared with others. This is due to the reduction of the number of nodes involved in the dissemination of RREQ packets which leads to the reduction of routing overhead and packet collisions. As a result, more communication bandwidth is freed for data transmission.

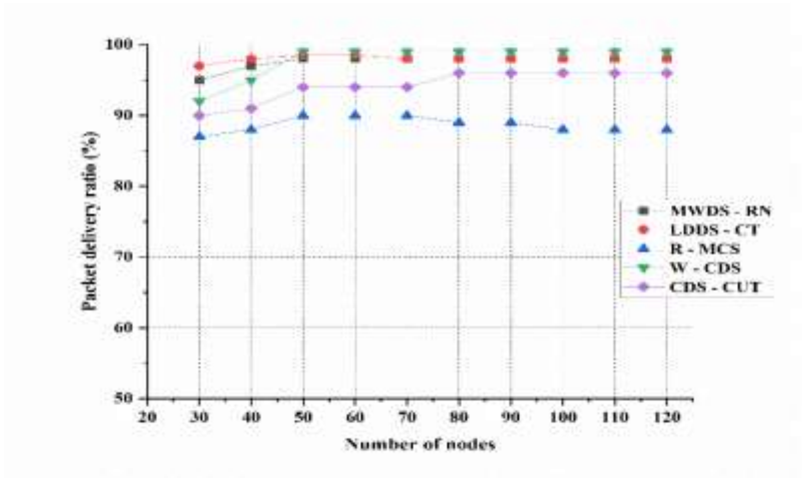

Figure 6 - Packet delivery ratio versus number of nodes

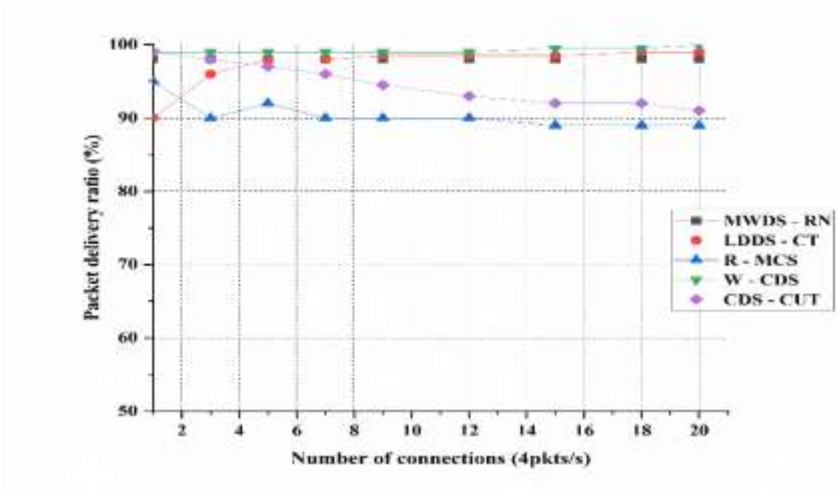

Figure 7 - Packet delivery ratio versus number of connections

4.2.5 Energy consumption

The Figure 8 depicts the average energy consumption of the nodes against node mobility. The energy consumption of the protocol increases with the increased node speed. More energy is consumed due to the frequent route reconstruction process resulting from link breakage. The W-CDS consumes less energy compared to others because of the reduction in routing overhead. When the speed is greater than 15 m/s, the frequent route breakage in R-MCS and other protocols lead to high energy consumption than W-CDS.

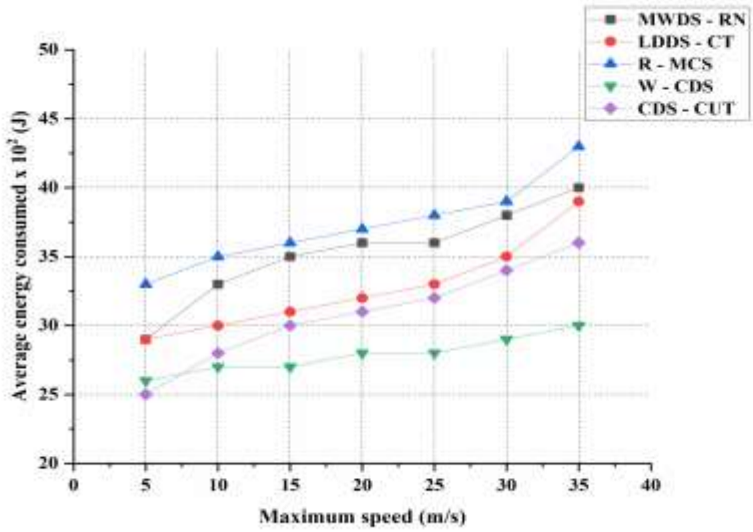

Figure 8 - Average energy consumption versus maximum speed

The route discovery operation works well with less number of nodes in the forwarding of RREQ packets and the route re-computation is less in W-CDS as shown in Figure 9. As a consequence, the energy consumption is minimized in W-CDS when compared with others.

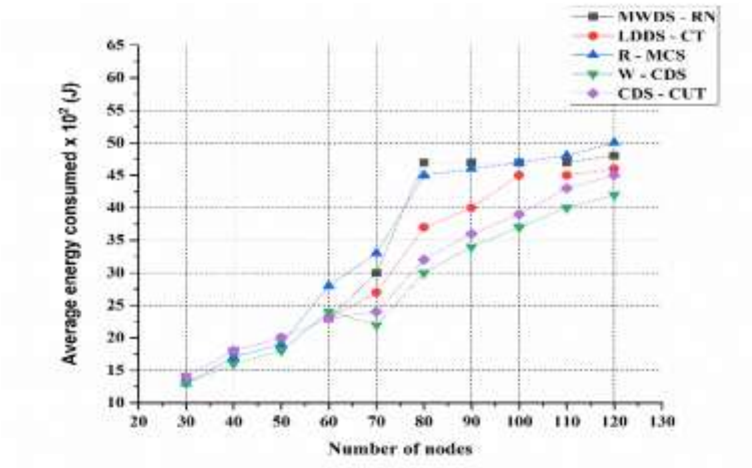

Figure 9 - Average energy consumption versus number of nodes

5 Conclusion

The distributed algorithm with weighted stability factor is proposed to obtain connected dominating set. These subsets of nodes are selected based on the stability factor, which consists of link stability, node degree and mobility. In order to improve the network lifetime,the nodes which satisfy the stability factor and those nodes with high residual energy are considered by pruning process for obtaining CDS. Hence, the simulation results show that the W-CDS outperforms other CDS based protocols such as LDDS-CT, CDS-CUT and MWDS-RN in terms of network lifetime and reduced fault nodes in routing. As the CDS nodes provide stability for a longer period of time, the topology change affects only the local nodes with less interference in the network. The proposed technique works well for high mobility rate and also for emergency and rescue operations.

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